Attar, Hani and Alhihi, Mohamad and Zhao, Bochao and Stankovic, Lina (2018) Network coding hard and soft decision behavior over the physical layer using PUMTC. In: 4th IEEE International Conference on Advances in Computing and Communication Engineering, 2018-06-22 - 2018-06-23. ,

Network Coding Hard and Soft Decision Behavior over the Physical Layer Using PUMTC

Hani Attar*, Mohamad Alhihi*
* Dept. Electronic and Communication
Philadelphia University
Amman, Jordan
Email: attar_hani@hotmail.com, alhihimohammad25@gmail.com

Bochao Zhao†, Lina Stankovic†
† Dept. Electronic and Electrical Engineering
University of Strathclyde
Glasgow, United Kingdom
Email: {b.zhao, lina.stankovic}@strath.ac.uk

***Abstract*—Network Coding (NC) is a technique applied to transmit combined packets rather than sending them separately, resulting in both data rate and bandwidth savings. In this paper, the behavior of hard and soft decision encoding/decoding is investigated using Partial Unit Memory Turbo Code (PUMTC) as the forward error correction method, over the physical layer when communication between users (nodes) is performed via an Amplitude and Forward (AF) Base Station (BS). NC is applied in the BS over the received packets before forwarding them to the destination. The simulation results show that soft decision encoding/decoding outperforms hard decision decoding, by around 0.4 dB which is regarded as a good improvement, taking into consideration that the system becomes less complex due to the removal of the hard decision block before decoding the received data in the BS and at the destination.**

***Index Terms*—Physical Layer, Forward Error Correction, Amplify and Forward.**

I. Introduction

Network Coding (NC) is a technique used to combine the data before sending them, resulting to better bandwidth and less traffic, which was proposed in [1]-[4]. NC can be applied over the physical layer by using the XOR operation to combine more than one packet, if we assume that we have equal length packets each with m bits; that means that multiple packets can be combined into one m-bit packet. So, sending one combined packet decreases the number of the transmitted packets and hence improves the transmission data rate [5]-[9]. Moreover, NC can be applied over erasure channels (data link layer), which improves the Packet Error Probability significantly [10]-[13]. Since NC has been applied to information transference for huge-sized and high-dimensional data, such as energy consumption data and billing information in Smart Grid, relative security and denoising issues have been investigated in previous research works [14]. Efficiency and complexity investigation among various NC schemes are raising more and more interests.

In this paper, NC is proposed to be applied over the physical layer, using both hard and soft decision, and hence a real and practical comparison between them is obtained, using Partial Unit Memory Turbo Code (PUMTC) as the forward error correction method. PUMTC codes were introduced by Lauer in 1979 [15]. PUM codes are multiple-input convolutional codes, which gives the optimal Maximum free distance versus the data rate and number of memory units and input bits. The main advantages of PUM code over classical convolutional codes are the reduced number of states in the trellis diagram for the same number of input encoder bits, and a larger free distance for the same trellis state complexity [15]. Because the number of memory units is more than zero and less than the number of the input bits, PUM codes holds an intermediate position between block (zero memory units) and convolutional codes (more memory units than input bits), as shown in [17].

Unlike [18], which proposed a method to decompose the general network to small building blocks of physical NC, the proposed work in this paper is directed to the general physical layer network with modifying the decoding process to obtain better decoding results. Though [19] introduced a novel idea to make the physical layer communication more reliable by using judiciously chosen linear error-correcting codes, or proposing intermediate nodes; this paper again did not introduce the principle of soft value decoding in the intermediate nodes.

As a result for the intermediate memory structure, PUM code has the properties of both block and convolutional codes enabling it to be suitable for many practical systems. Moreover, the non-binary inputs and outputs of PUM codes enhance a larger flexibility for the generation of rate-compatible and adaptive codes [17]. The rest of the paper is as follows: Section II explains the proposed system. Section III illustrates the simulation results, and finally, section IV concludes the work.

II. Network Coding over Physical Layer

In this contribution, we propose a practical power- and bandwidth-efficient system based on Amplify and Forward (AF) scheme to address the problem of information exchange via a relay. The key idea is to channel encode each sources message by using PUMTC codes to enhance the bit-error-rate performance, then reduce the energy consumption and increase spectrum efficiency by using NC to combine individual nodes messages at the relay. The low complexity physical layer NC scheme proposed in this work is based on spatial and temporal combinations of received source messages at the relay. The Simulation results is collected under Additive White Gaussian Noise (AWGN), which confirm that the proposed schemes achieve significant bandwidth savings and fewer transmissions over the benchmark systems which do not resort to NC. Capacity theoretical limits and behaviour at Signal to Noise Ratio (SNR) for the proposed schemes is shown in [11]. The way PUMTC is implemented in the proposed hard and soft decoding systems is shown in Figs. 1 and 2, respectively.

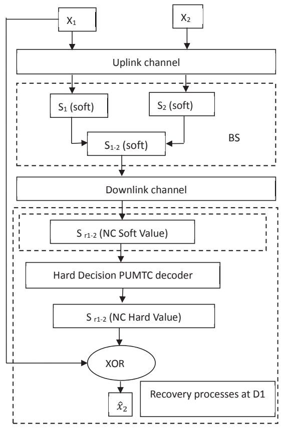

Fig. 1. Hard decision decoding for Network Coding proposed system.

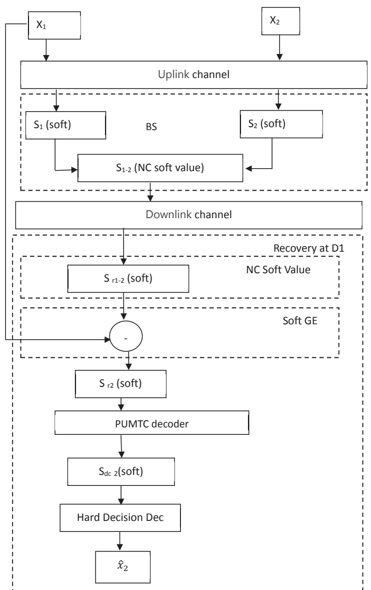

Fig. 2. Soft decision decoding for Network Coding proposed system. GE denotes Gaussian Elimination.

The encoded packet x_i is sent to the BS through the Up-Link channel (UL) to be received as a soft value packet, i. e., the transmitted packet added to AWGN as shown in (1):

$$s_i = x_i + z_i^{UL}, \tag{1}$$

where s_i is the received soft value in the BS and z_i^{UL} is the uplink i.i.d. Gaussian noise of unit power independent of the source signals.

When NC is not applied, the BS only amplifies the received soft value before forwarding to the destination. Accordingly, the received soft value at the destination is shown in (2):

$$\hat{s}_i = A_{AF} s_i + z^{DL} = A_{AF}(x_i + z_i^{UL}) + z^{DL}, \tag{2}$$

where $\hat{s}_i$ is the received soft value, $A_{AF} \geq 1$ is the amplification factor at the BS, and z^{DL} represents AWGN in the Down-Link (DL).

When applying NC in the BS for two users as an example, the BS applies NC over soft values (Figs. 1 and 2), and then send combine soft value packet to the destination, as shown in (3):

$$\begin{aligned} s_{1-2} &= A_{AF_p}(x_1 + z_1^{UL} + x_2 + z_2^{UL}) \\ &= A_{AF_p}(s_1 + z_1^{UL} + s_2 + z_2^{UL}), \end{aligned} \tag{3}$$

Where s_{1-2} is the transmitted soft value combined packet, which is sent from the BS to the destination.

In the case of hard decision values (Fig. 1), the destination uses a hard decision decoder over the received packets, XORing the resulting packets to retrieve the desired packet. Accordingly, the network coded packet received at the destination is shown in (4):

$$\begin{aligned} s_{r1-2} &= A_{AF_p}(x_1 + z_1^{UL} + x_2 + z_2^{UL}) + z_{1-2}^{DL} \\ &= A_{AF_p}(s_1 + s_2) + z_{1-2}^{DL}, \end{aligned} \tag{4}$$

where $A_AF_p \geq 1$ is the amplification factor applied in the BS over the noisy combined packet, and s_{r1-2} is the received soft value at the destination. As a result, the retrieved packet at the destination is given by (5):

$$\hat{x}_1 = \hat{x}_{1-2} \oplus x_2, \tag{5}$$

where $\hat{x}_1$ is the retrieved packet from which sent from the first destination at the second destination, and $\hat{x}_{1-2}$ is the hard decision decoded combined packet at the second destination.

In the soft decision scenario (Fig. 2), the receiving destination performs soft decision decoding directly over the received soft value of the combined packet without applying the hard decision decoding, as a result, the PUM turbo decoder soft value for the combined packet is then used to retrieve the soft value of the desired information packet as shown in (6):

$$s_{r2(soft)} = s_{r1-2(soft)} - x_2, \tag{6}$$

The soft value of $s_{r2(soft)}$ is then passed to hard decision decoder to retrieve the desired final information data.

It is noticeable that using hard decision results in losing information through the hard decision decoding process, hence the second design is proposed to avoid this leak of information as shown in Fig. 2.

It is clear that using soft decision simplifies the system as there is no need to re-encode and modulate the estimated data. Finally, we could use both designs as a way of error detection, i.e. obtain the same results by the two different designs and then compare the result. In the case that both designs give the same output, we confirm it as a final result, but when the result is different, we can consider this as error detection evidence, hence, we re-decode the received data. As our research is aimed at NC, we leave this research point at this level and just show the BER results for both designs.

III. Simulation Results

We use Partial Unit Memory Turbo codes (PUMTC) introduced in [17] and showing capacity approaching performance via EXIT charts in [20]. In our systems, transmission is simulated over AWGN, using BPSK modulation for rate 1/3 PUMTCs based on (4,2,1,4) PUM component codes, and a pseudo-random interleaver of size 1000 bits. We set the transmitted signal amplitude AF=4 and four decoding iterations for the simulation run as it gives the best average results. The BER performance curves are obtained by simulating transmission of at least 108 bits with at least 100 bit errors for statistical significance.

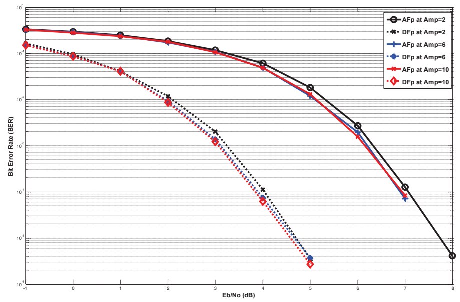

Fig. 3. AF and DF systems based on (4,2,1,4)-PUMTC with 4 decoding iterations. The figure demonstrates the effect of increasing the amplification factor [7].

Fig. 3 shows the normal behavior for PUMTC (4,2,1,4) when changing the Amplification factor (AF) for Amplify and Forward (AF) Base Station (BS), and Decode and Forward (DF) BS. It is clear that decoding the data in the BS before forwarding them improves the Bit Error Rate (BER) significantly, however, the PUMTC encoder-decoder processing time increase together with the system complexity.

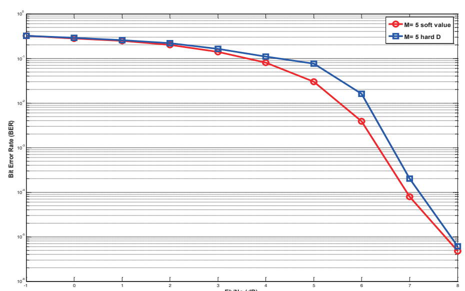

Fig. 4. BER for Soft and hard decision decoding for AF$_p$ (4,2,1,4) at $M = 5$.

Fig. 4 shows the decoding performance for the propose AF when $M = 5$, which means that we have five nodes exchange their data through the relay. Both soft value and hard values have been performed, and results show that soft value decoding gives better performance, mainly at high BER values, this gap reaches 0.4 dB at BER of 104, and the gap goes as small as just 0.15 dB at BER of 10^5.

IV. Conclusion

In this paper, applying Network Coding (NC) over the physical layer is proposed using Partial Unit Memory (PUM) code. Both hard and soft decision decoding is performed over Amplify and Forward relay using (4,2,1,4) PUM components, and the results show that the soft decision decoding system outperforms the hard decision by 0.4 dB without causing any extra complexity for the system. This improvement is justified by the fact that the soft decision decoder does not lose any amount of the received information, unlike the hard decision where the decoder loses valuable amount of information when using the hard decision decoding before passing the information to PUM decoder to obtain the recovered data.

References

[1] R. Ahlswede, N. Cai, S. Y. Li, and R. W. Yeung, "Network Information Flow", *IEEE Transactions on Information Theory*, vol. 46, no. 4, pp. 1204–1216, Jul. 2000, https://doi.org/10.1109/18.850663.

[2] X. Bao, and J. Li, "A Unified Channel-Network Coding Treatment for User Cooperation in Wireless Ad-Hoc Networks", in *Proceedings of IEEE ISIT-2006*, pp. 202–206, Seattle, WA, USA, 9–14 Jul. 2006, https://doi.org/10.1109/isit.2006.261833.

[3] Y. Wu, P. A. Chou, and S. Y. Kung, "Information Exchange in Wireless Networks with Network Coding and Physical-Layer Broadcast." in *Proc. CISS*, Baltimore, Mar. 2005.

[4] V. Stankovic, L. Stankovic, A. Moinian, and S. Cheng, "Wireless Full-Duplex Communications Based on Network Coding." in *Proc. 45th Annual Allerton Conference on Communications, Control and Computing*, Monticello, Sep. 2007.

[5] S. Katti, I. Maric, D. Katabi, A. Goldsmith, and M. Medard, "Joint Relaying and Network Coding in Wireless Networks", in *Proc. ISIT-2007*, France, 24–29 Jun. 2007, https://doi.org/10.1109/isit.2007.4557120.

[6] H. Attar, L. Stankovic, and V. Stankovic, "Physical-Layer NC Based on PUM Turbo Codes". in *IEEE Mosharaka International Conference on Communications, Signals and Coding*, Amman, 6–8 Feb. 2009.

[7] H. Attar, and L. Stankovic, and V. Stankovic, "Cooperative Network-Coding System for Wireless Sensor Networks", *IET Communications*, vol. 6, no. 3, pp. 344–352. Feb. 2012.

[8] H. Attar, "Data Combination over Physical Layer Using Network Coding with PUM Turbo Codes", *Journal of Computer and Communications*, vol. 5, no. 06, pp. 32–44. Apr. 2017, https://doi.org/10.4236/jcc.2017.56002.

[9] H. Attar, "Physical Layer Deterministic Network Coding Using PUM Turbo Codes over AWGN Channel, N Nodes through a Base Station Scenario", *Communications and Network*, vol. 8, no. 04, pp. 241–256, Sep. 2016, http://dx.doi.org/10.4236/cn.2016.84022.

[10] H. Attar, D. Vukobratovic, L. Stankovic, and V. Stankovic, "Performance Analysis of Node Cooperation with NC in Wireless Sensor Networks", in *4th IEEE International Conference on New Technologies, Mobility and Security*, Paris, pp. 7–10, Feb. 2011.

[11] M. El–Hihi, and H. Attar, A. Solyman, and L. Stankovic, "Network Coding Cooperation Performance Analysis in Wireless Network over a lossy Channel, M Users and a Destination Scenario", *Communications and Network*, vol. 8, no. 04, pp. 257–280, Sep. 2016, https://doi.org/10.4236/cn.2016.84023.

[12] H. Attar, "Half-Cycle Transmission Cooperative Network Coding for Wireless Sensor Network over Erasure Channels", *Jordan Journal of Electrical Engineering*, Vol. 3, no. 4, pp. 236–248, Dec. 2017, ISSN (Print): 2409-9600, ISSN (Online): 2409-9619, http://www.ttu.edu.jo/jjee/docs/Vol3no4/JJEE%20vol.%203,%20no.%204,%20pp.%20236-248.pdf.

[13] H. Attar, L. Stankovic, M. Al–Hihi, and A. Solyman, "Deterministic network coding over long term evaluation advance communication system", in *Proc. Intl. Conf. on Digital Info, and Comm. Technology and its Applications*, pp. 56–61, May 2014.

[14] D. Murray, B. Zhao, G. Elafoudi, J. Liao, L. Stankovic, and V. Stankovic, "Combined network coding and paillier homomorphic encryption for ensuring consumer data privacy in smart grid networks", Abstract from *Algebra, Codes and Networks 2014*, Bordeaux, France, Jun. 2014.

[15] G. Lauer, "Some optimal partial unit-memory codes", *IEEE Transactions on Information Theory*, vol. 25, pp. 240-243, Mar. 1979.

[16] C. Nelson, L. Stankovic, V. Stankovic and S. Cheng, "Performance Analysis of PUM codes", in *Proc. 5th Intl. Symposium on Turbo Codes & Related Topics*, Lausanne, Switzerland, pp. 260–265, Sep. 2008.

[17] L. Fagoonee, and B. Honary, "Construction of Partial Unit Memory Encoders for Application in Capacity-Approaching Concatenated Codes", in *IEE Proc. Comm,: Special Section on Capacity Approaching Codes, Design and Implementation*, vol. 152, no. 6, pp. 1108–1115, Dec. 2015.

[18] J. He, and S. C. Liew, "Building blocks of physical-layer network coding", *IEEE Transactions on Wireless Communications*, vol. 14, no, 5, pp. 2711–2728, May 2015.

[19] B. Nazer, and M. Gastpar, "Reliable physical layer network coding", in *Proc. the IEEE*, vol. 99, no. 3, pp. 438–460, Mar. 2011.

[20] C. J. Nelson, L. Stankovic, and B. Honary, "Partial-Unit Memory based Turbo Codes", *IET Electronics Letters*, vol. 45, no. 21, pp. 1081–1082, Oct. 2009.